MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2018/2019

ENT4046 – N/MEMS

(NE)

7 MARCH 2019
9:00 a.m. - 11:00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 5 pages with 4 Questions only.
2. Attempt **ALL FOUR** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. Please refer to page 4 and 5 for the List of Formulas and the Appendix.

QUESTION 1

(a) (i) Explain a major advantage of MEMS/NEMS as compared to microelectronics.
[2 marks]

(ii) List **FOUR(4)** figures of merits for MEMS/NEMS.
[2 marks]

(iii) With a simple diagram, show the mechanical sensing scheme of a silicon-die micropressure sensor.
[4 marks]

(b) (i) List **FOUR(4)** common geometries for mechanical sensors and give **ONE(1)** example for each geometry.
[4 marks]

(ii) Explain briefly **TWO(2)** applications of electrostatic/ capacitive effect.
[4 marks]

(c) Discuss briefly the **THREE(3)** main levels of packaging strategy that may be adaptable for MEMS packaging.
[9 marks]

QUESTION 2

(a) (i) A 600 μm × 600 μm square germanium diaphragm is loaded with pressure at 25 MPa. Calculate the thickness of the diaphragm if the maximum deflection of the diaphragm is 30 μm. Given that Young's modulus value for germanium is 140 GPa.
[4 marks]

(ii) Subsequently, calculate the maximum stress of the diaphragm.
[4 marks]

(b) With the aid of diagram, explain briefly the working principles of a sensor using vibrating beam.
[3+6 marks]

(c) A bilayer strip is fabricated using gold and silicon as shown in **Figure Q2(c)**. Given that Young's modulus of gold and silicon are 79 GPa and 190 GPa, respectively; and thermal expansion coefficient of gold and silicon are 14.2×10^{-6} /°C and 2.33×10^{-6} /°C, respectively.

(i) Calculate the interfacial force of strip at 20 °C.
[4 marks]

(ii) Calculate the radius of curvature of the strip at 30 °C.
[4 marks]

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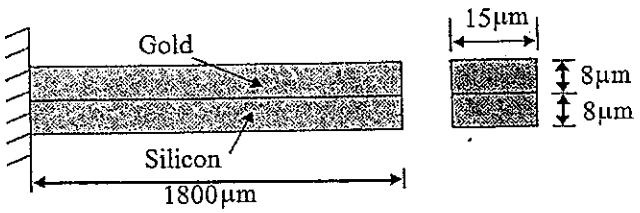

Figure Q2(c)

QUESTION 3

(a) With the aid of diagram, explain briefly the working principle of an electrostatic rotary side-drive motor. Label clearly all the directions of electrostatic charges and movements in the diagram.

[7+5 marks]

(b) A longitudinal piezoresistor is embedded on the top surface of a fixed-free single-crystal silicon cantilever near the fixed end. The piezoresistor is *p*-type doped with resistivity of 7.8 Ωcm. The longitudinal axis of the cantilever points in the <111> direction. The length, width, and thickness of the cantilever are 150 μm, 15 μm, and 5 μm, respectively. The Young's modulus of single-crystal silicon is 189 GPa in the <111> direction. Calculate the following respectively:

- Longitudinal piezoresistive coefficient, π_l,
- Longitudinal gauge factor, G,
- Induced strain, s, and
- Change of resistance, $\Delta R/R$, when a force of 50 μN is applied.

[13 marks]

QUESTION 4

(a) (i) Describe briefly laminar flow in microfluidic device.

[3 marks]

(ii) Given the Hagen-Poiseuille law, $\Delta P = \frac{8\mu L Q}{\pi a^4}$, and the volumetric fluid flow, $Q = A_s V_{avg}$, where ΔP is the pressure drop, μ is the dynamic viscosity, L is the length, a is the tube radius, A_S is the cross-sectional area, and V_{avg} is the average velocity. Estimate the variations in volumetric flow (Q) and pressure drop per unit length ($\Delta P/L$) in a circular tube, respectively, if the radius of the tube is reduced by a factor of 10.

[6 marks]

Continued...

(b) With aid of diagrams, illustrate the process steps in micromaching of a *free-standing microstructure* and a *three-dimensional feature*, using sacrificial surface and LIGA process, respectively.

[12 marks]

(c) Name **FOUR(4)** types of reliability issues.

[4 marks]

List of Formulas:

$w_{\max} = -\frac{0.0138pa^4}{Eh^3}$	$\sigma_{\max} = \frac{0.308pa^2}{h^2}$
$w_{\max} = -a\frac{pb^4}{Eh^3}$	$(\sigma_{yy})_{\max} = \beta\frac{pb^2}{h^2}$
$W_{\max} = -\frac{3W(m^2-1)a^2}{16\pi Em^2h^3}$	$(\sigma_{rr})_{\max} = \frac{3W}{4\pi h^2}$
$\delta = \frac{FL^3}{3EI}$	$c = 16f\left(\frac{W}{L}\right)W^3LH_o^3$
$k = \frac{F}{\delta} = \frac{3EI}{L^3}$	$c = \frac{2\mu Lb}{H}$
$I = \frac{bh^3}{12}$	$\rho = \frac{2h}{3(\alpha_2-\alpha_1)T}$
$F = \frac{(\alpha_2-\alpha_1)T}{8}\frac{hb}{\left(\frac{1}{E_1}+\frac{1}{E_2}\right)}$	$C = \frac{\varepsilon_r\varepsilon_o A}{d}$
$F_d = -\frac{\varepsilon_r\varepsilon_o WLV^2}{2d^2}$	$F_W = \frac{\varepsilon_r\varepsilon_o LV^2}{2d}$ or $F_L = \frac{\varepsilon_r\varepsilon_o WV^2}{2d}$

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Appendix:

Table of Interpolation for Numerical Values of the Function f(W/L) Versus W/L.

W/L	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
f(W/L)	1	0.992	0.984	0.976	0.968	0.960	0.952	0.944	0.936	0.928	0.920

Table of Piezoresistivity Components for Single-Crystal Silicon under Certain Doping Values.

Piezoresistance coefficient ($10^{-11}Pa^{-1}$)	n-type (resistivity = 11.7 Ωcm)	p-type (resistivity = 7.8 Ωcm)
π_{11}	−102.2	6.6
π_{12}	53.4	−1.1
π_{44}	−13.6	138.1

Formula for Transverse and Longitudinal Gauge Factors for Various Commonly Encountered Resistor Configurations.

Direction of strain	Direction of current	Configuration	Piezoresistive coefficient
<100>	<100>	Longitudinal	π_{11}
<100>	<010>	Transverse	π_{12}
<110>	<110>	Longitudinal	$(\pi_{11} + \pi_{12} + \pi_{44})/2$
<110>	<1$\bar{1}$0>	Transverse	$(\pi_{11} + \pi_{12} - \pi_{44})/2$
<111>	<111>	Longitudinal	$(\pi_{11} + 2\pi_{12} + 2\pi_{44})/2$

End of Paper